



*... for a brighter future*



U.S. Department  
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Argonne<sub>LLC</sub>

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# ***Electron microscopy and nanoscience at Argonne: New opportunities through TEAM***

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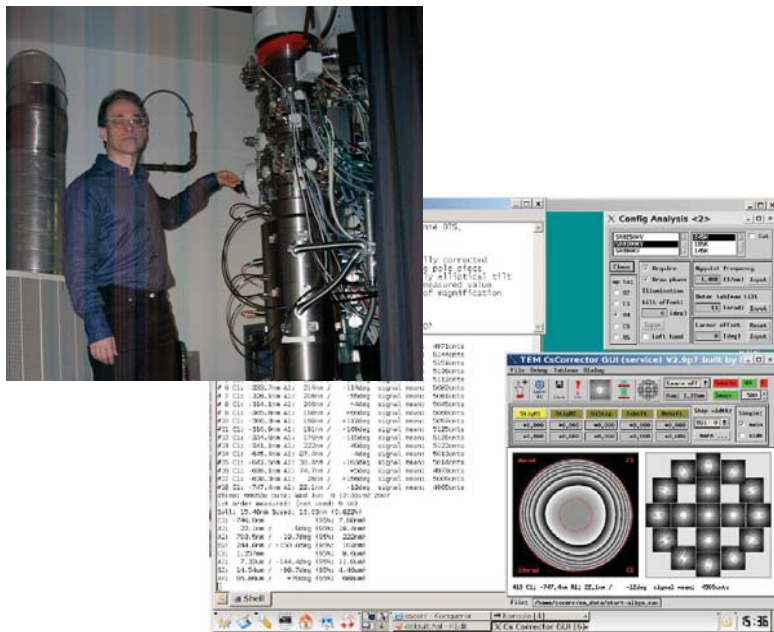
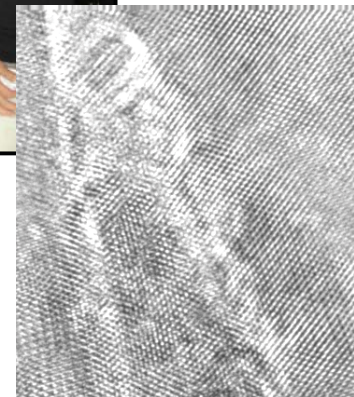
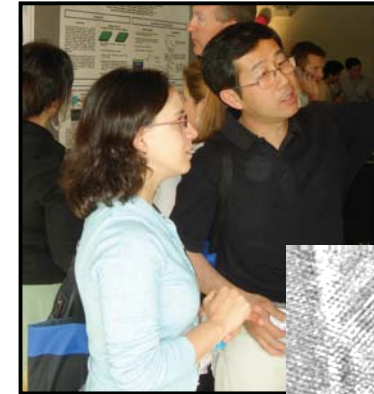
*Supported by the U. S. Department of Energy, Office of Science -  
Basic Energy Sciences, under Contract W-31-109-ENG-38.*

*Workshop on Extending the TEAM Control Room*

**Materials Science Division  
Electron Microscopy Center**

# How will “remote” TEAM impact science at ANL ? ... and how can remote operation impact TEAM ??

- Teams of scientists engaged in world class science can access unprecedented capabilities of TEAM



- Remotely located experts can help optimize and facilitate operation of TEAM

# Electron microscopy and nanoscience at Argonne

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The ***Electron Microscopy Center*** is the focal point for electron microscopy and scattering at Argonne and for a large user community.

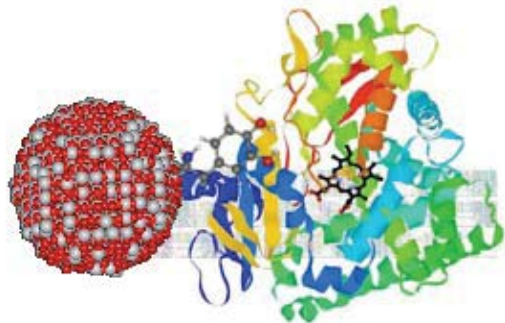


The ***Center for Nanoscale Materials*** is the home for the development and dissemination of the techniques for synthesis, fabrication, characterization and theory of nanomaterials

*The EMC and the CNM work closely together to meet the microscopy needs of their users –from characterization of new materials to “heroic” microscopy studies*

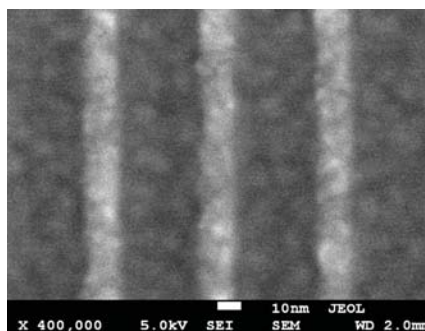
# CNM Research Themes

## NanoBio Interfaces



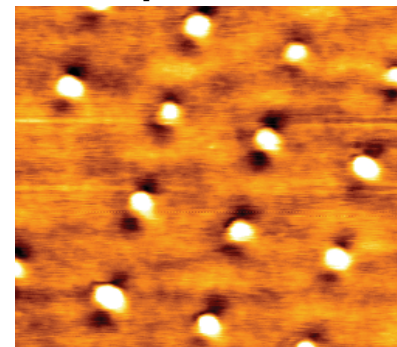
Create bio-inspired materials and processes for energy transduction

## Nanofabrication



Discover new paths for nanostructured materials, including below 10 nm

## Nanophotonics



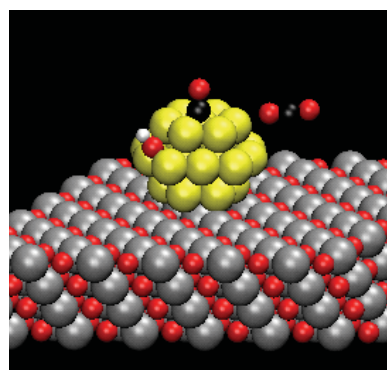
Understand and control optical energy pathways

## X-ray Microscopy



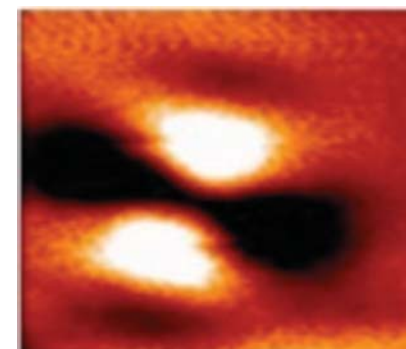
Create images of the nanoworld with hard x-rays

## Theory & Modeling



Towards the 'virtual fab lab'

## Electronic & Magnetic Materials



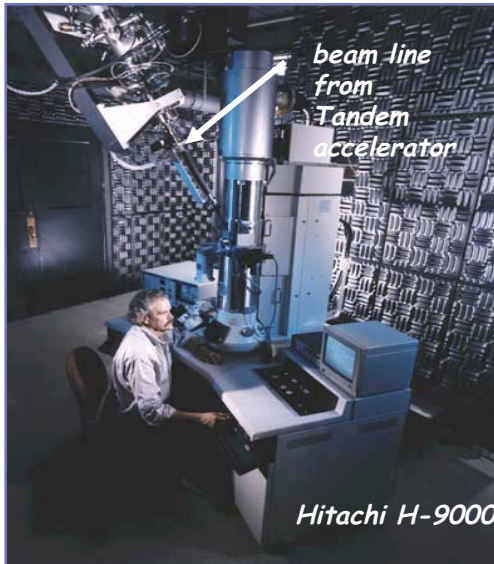
Understand and control charge and spin-based materials for energy and information transport



# EMC Resources and Capabilities for Research

The EMC currently supports six major instruments for scientific research

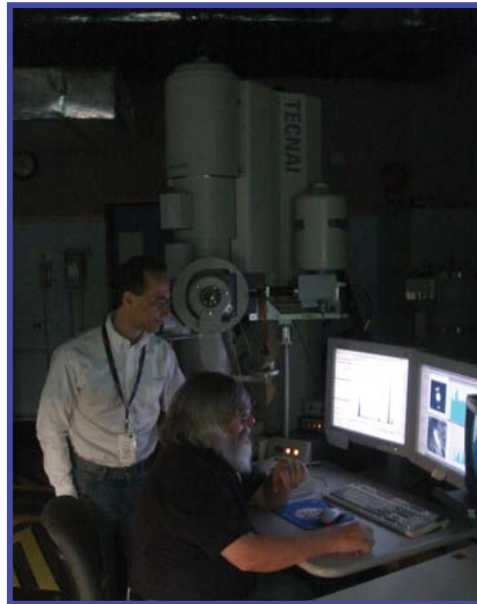
- TEM & SEM



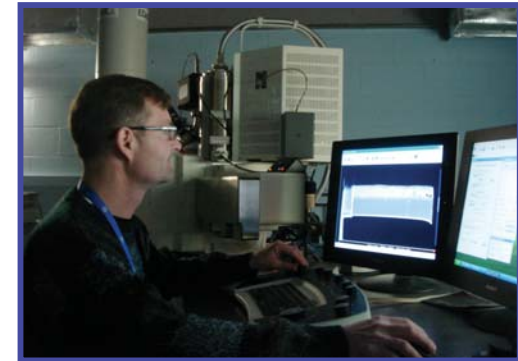
IVEM-Tandem facility  
- unique capabilities for studying ion-solid interactions

- High-resolution SEM
- Analytical TEM

Zeiss FIB-SEM  
- focused ion beam (FIB) w/ SEM →

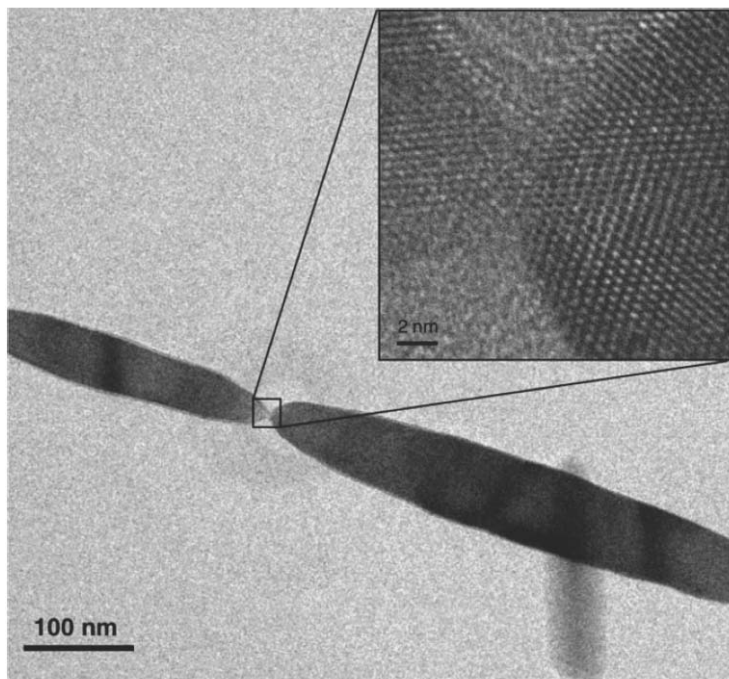


FEI Tecnai F20  
- state-of-the-art field-emission gun TEM and STEM



FEI Quanta 400F ESEM  
- Environmental SEM with capability for **in-situ studies**

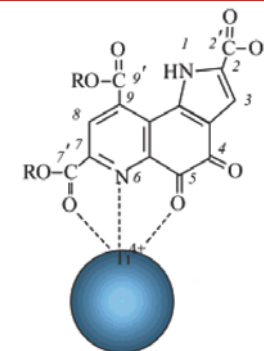
# NanoBio Interfaces – functionalized nanoparticles



**Figure 3.** TEM image of anisotropic  $\text{TiO}_2$  nanoparticles functionalized with biotin and coupled together through avidin. The inset shows a high-resolution image of the coupled nanorods with enhanced contrast seen in the region between the two tips.

Functionalized  $\text{TiO}_2$  nanorods,  
from B. Rabatic et al., *Adv. Mater.* **18**, 1033 (2006)

Tridentate complex of  $\text{Ti(IV)}_{\text{surface}}$  on a  $\text{TiO}_2$   
nanoparticle, with pyrroloquinoline quinone,  
from N.M. Dimitrijevic et al., *J. Phys. Chem. B* **100**,  
25392 (2006)



## Key Scientific Questions:

- ◆ Statics and dynamics of field distributions (electric, magnetic) and charge/spin transport
- ◆ Atomic resolution physical, chemical and electronic structure at hybrid materials interfaces

## How TEAM can help:

- ◆ Reducing/eliminating damage during imaging and analysis - lower keV with high resolution
- ◆ Increased analytical sensitivity
- ◆ Small probes with high current
- ◆ Space for sample environments & for sample rotation to multiple orientations
- ◆ Better contrast for low-Z materials

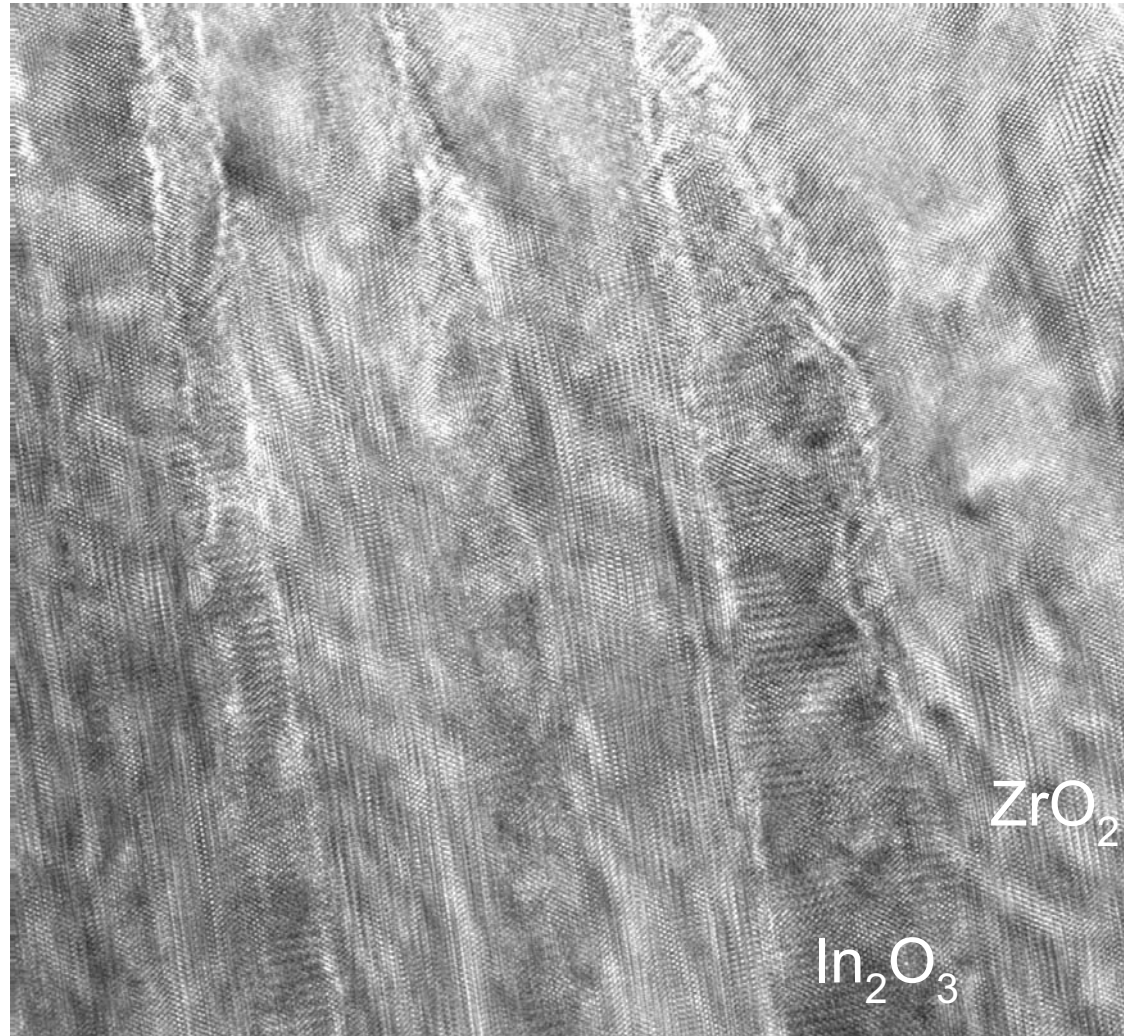


# *Electronic & Magnetic Materials: Digital synthesis*

Novel behavior in heterostructures probed by digital synthesis: e.g. transparent conducting oxides

## **Key Scientific Questions:**

- ◆ Atomic resolution of layer structure and defects
- ◆ 3-D structure of interfaces
- ◆ field distributions (electric, magnetic) and proximity interactions



# Digital synthesis of transparent conducting oxides

## How TEAM can help:

- ◆ Atomic resolution and high sensitivity
- ◆ Reducing delocalization effects
- ◆ 3-D structure— avoid the projection problem

Reconstructed  
Phase

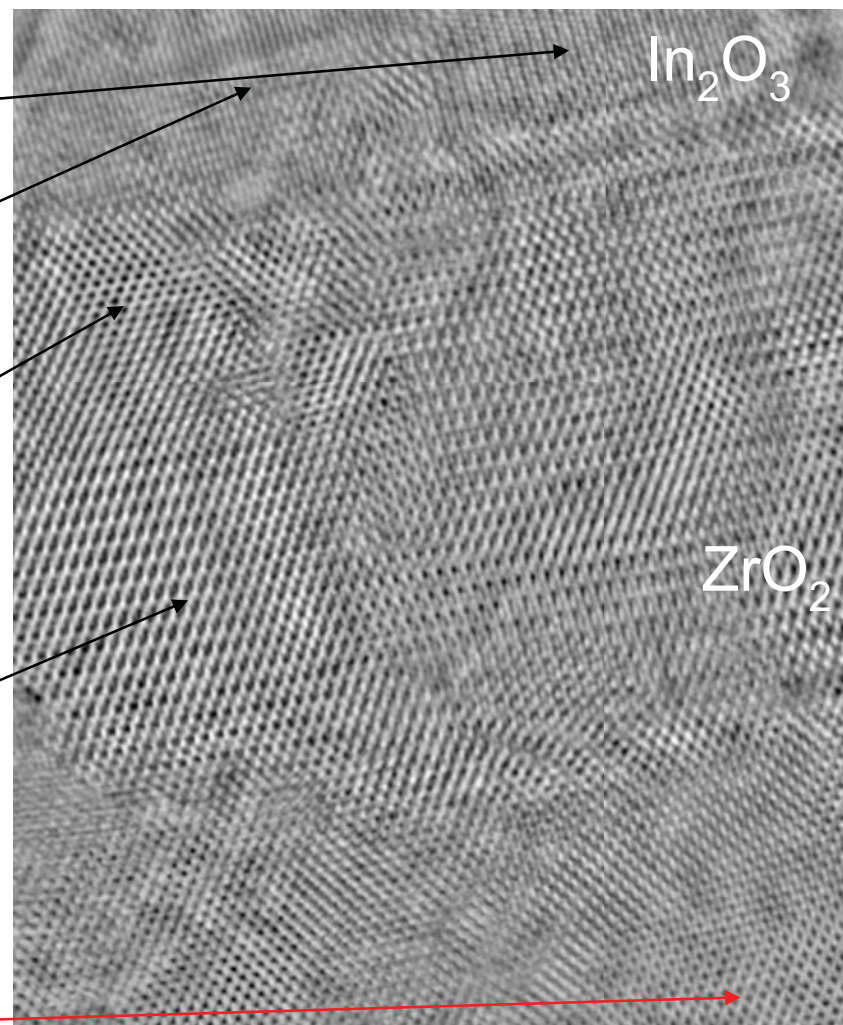
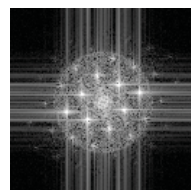
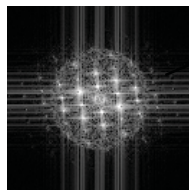
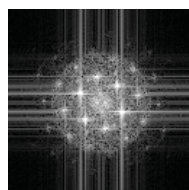
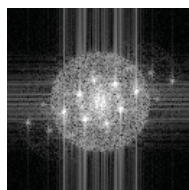
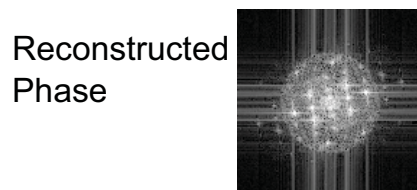
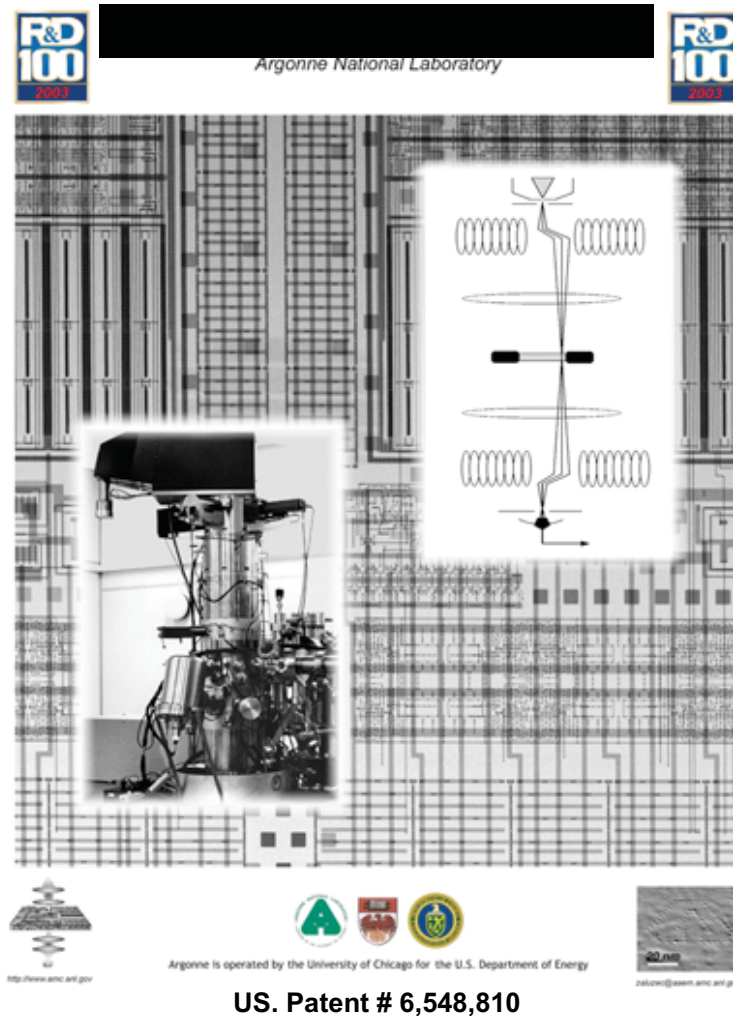


Image reconstruction



# Scanning Confocal Electron Microscopy (SCEM)

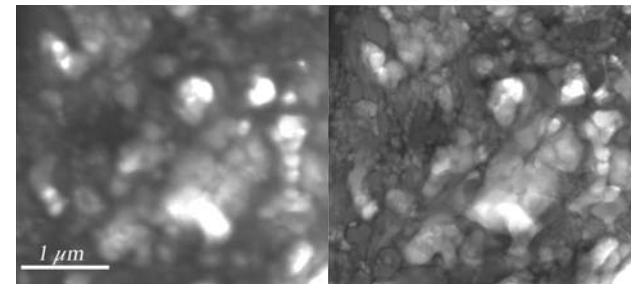


- Many real world problems require excellent resolution (but not atomic scale) but in thicker materials
- Others require depth resolution which is facilitated by confocal operation
- SCEM provides these capabilities and bridges the gap between HREM and STXM

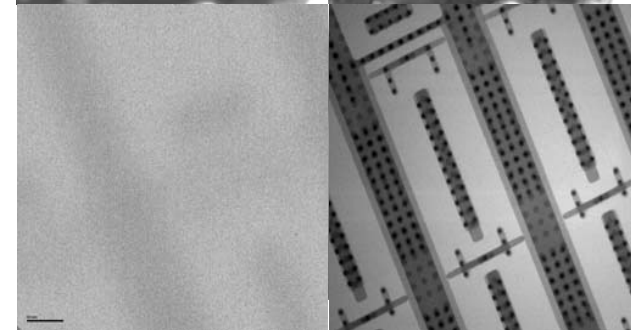
TEM

SCEM

Life  
Science



Materials  
Science

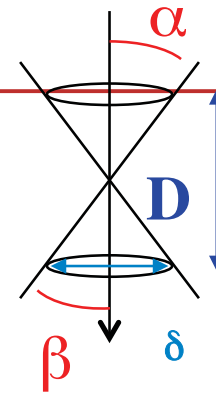


> 3 micron thick sections

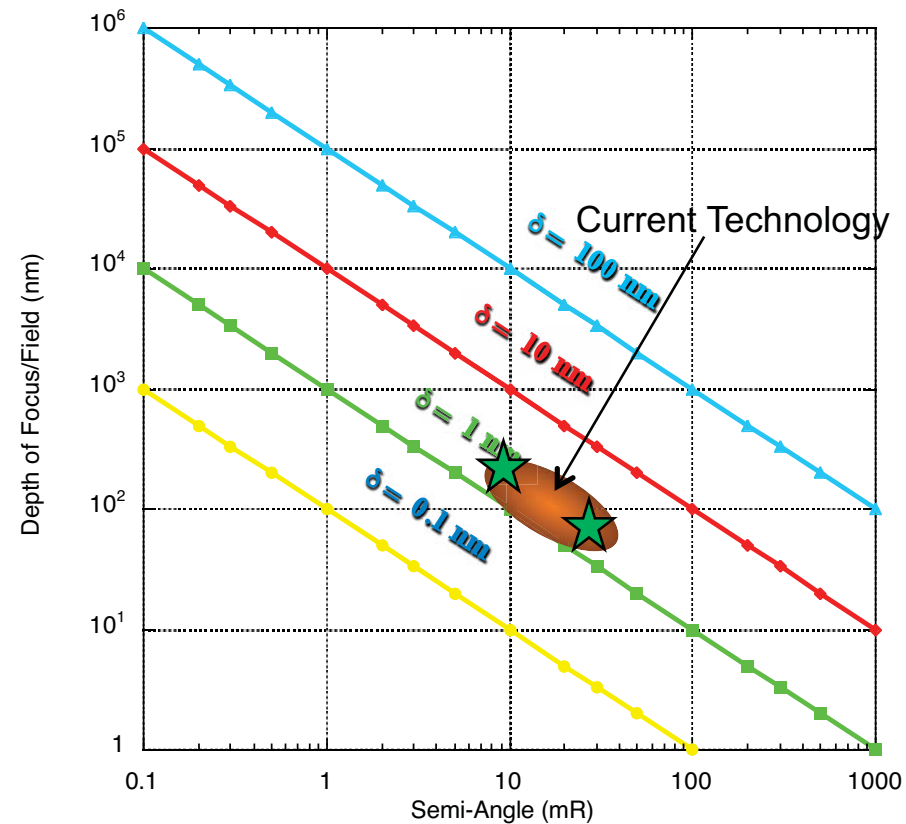
# SCEM

## How TEAM can help:

- improve spatial & depth resolution (functions of pre/post specimen illumination and collection angles :  $\alpha$  &  $\beta$ )
- New operating modes need to be developed to optimize functionality these are NOT found in standard implementations of existing instruments

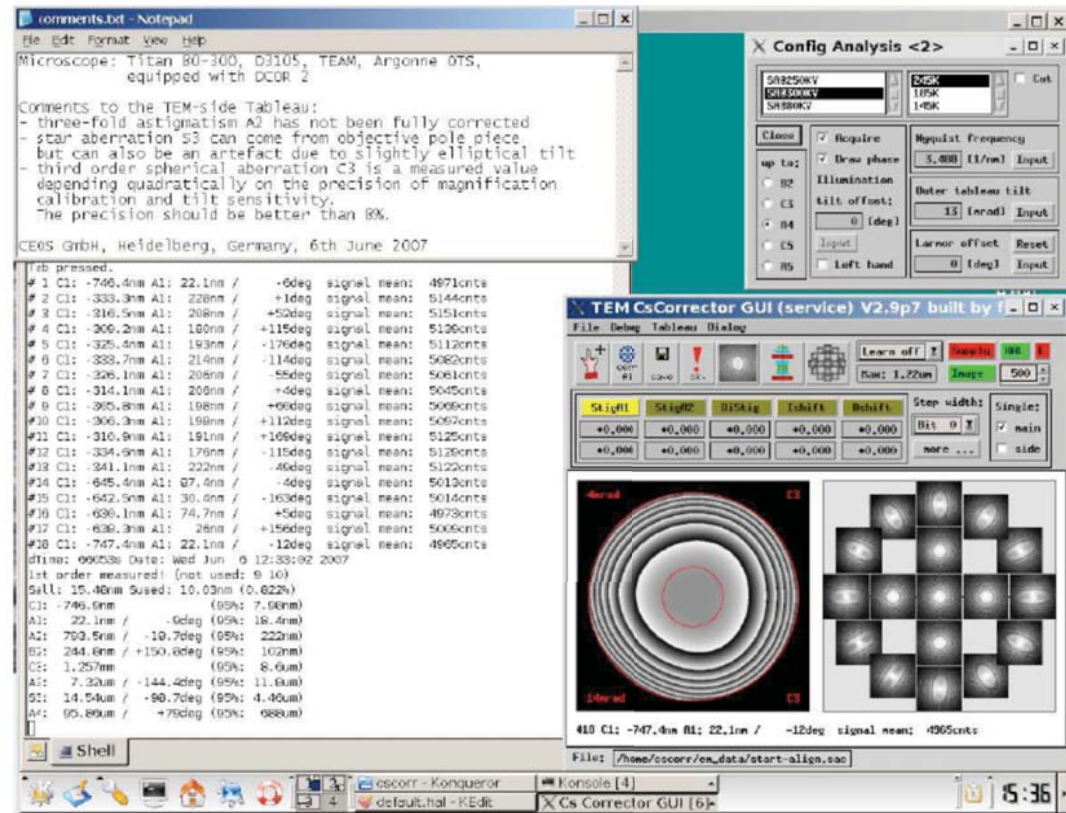


$$D = \frac{\delta}{\alpha}$$



# Optimizing TEAM through remote access

Remote experts can help optimize performance of TEAM and troubleshoot issues

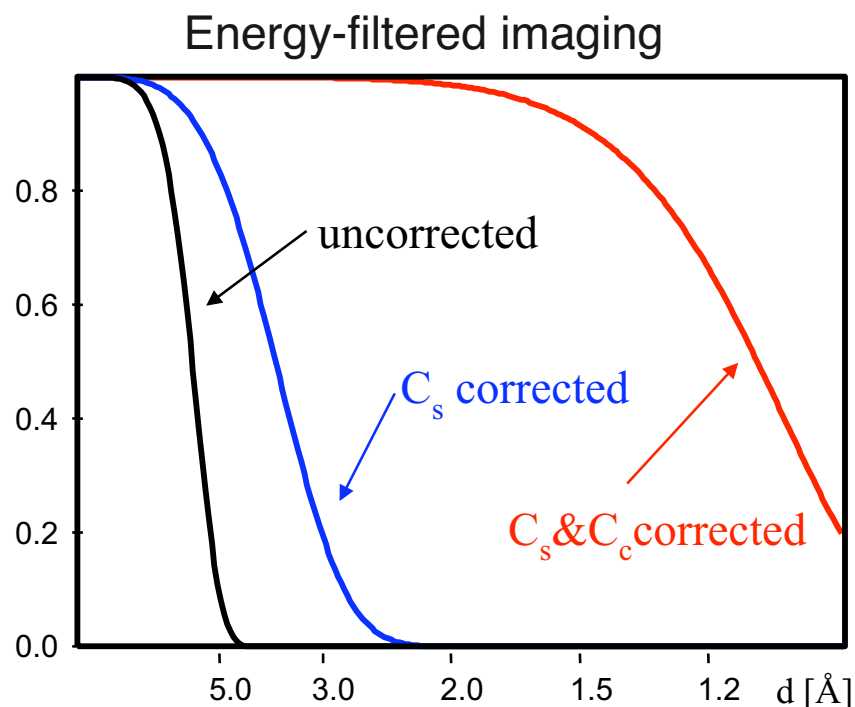


The interface for TEAM is intended to be simple and easy-to-use for all users, but occasional higher-level intervention may be needed



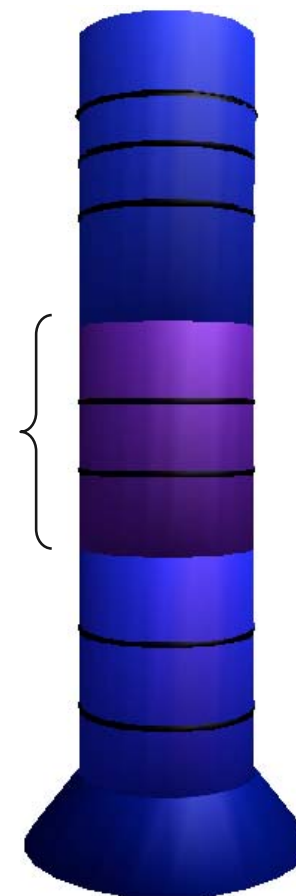
# New Opportunities through TEAM

Aberration correction is leading to new scientific opportunities



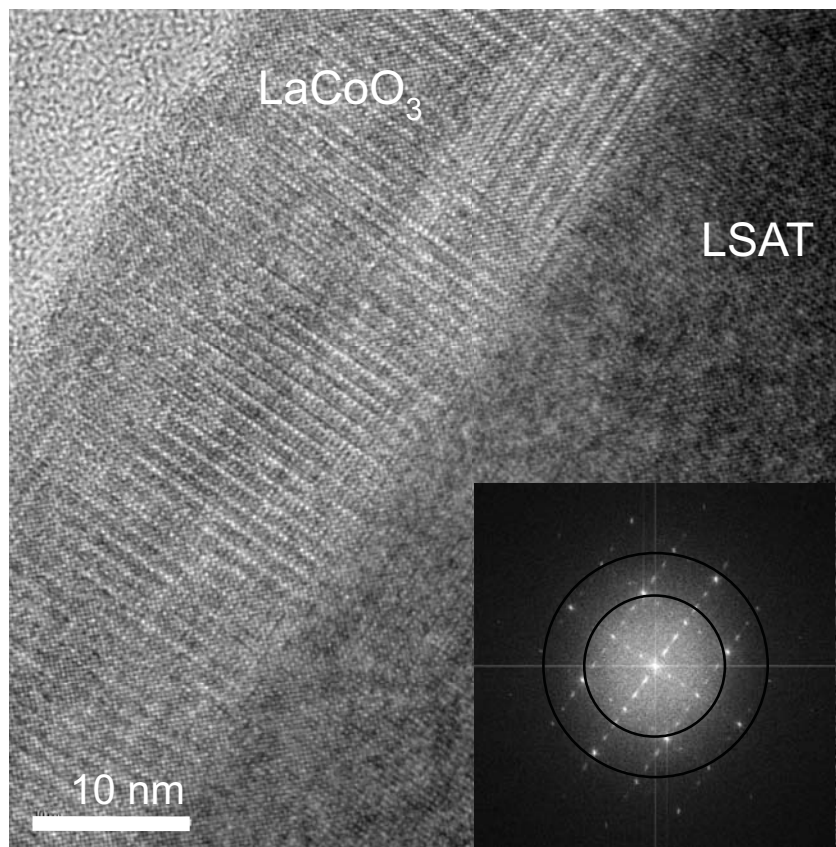
**Aberration-correcting optics and high stability stage** are key steps toward **atomic scale resolution**

Contrast transfer damping envelope for ***energy-filtered imaging (chemical contrast)***

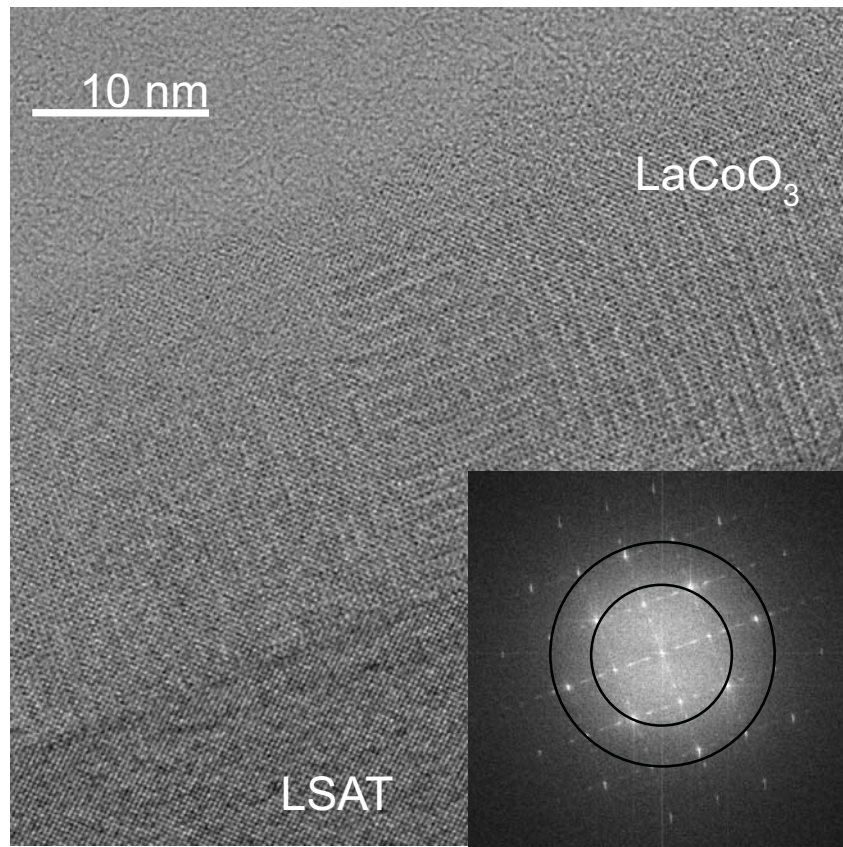


# World's first demonstration of chromatic aberration correction for TEM

## TEAM $C_c$ -corrector prototype



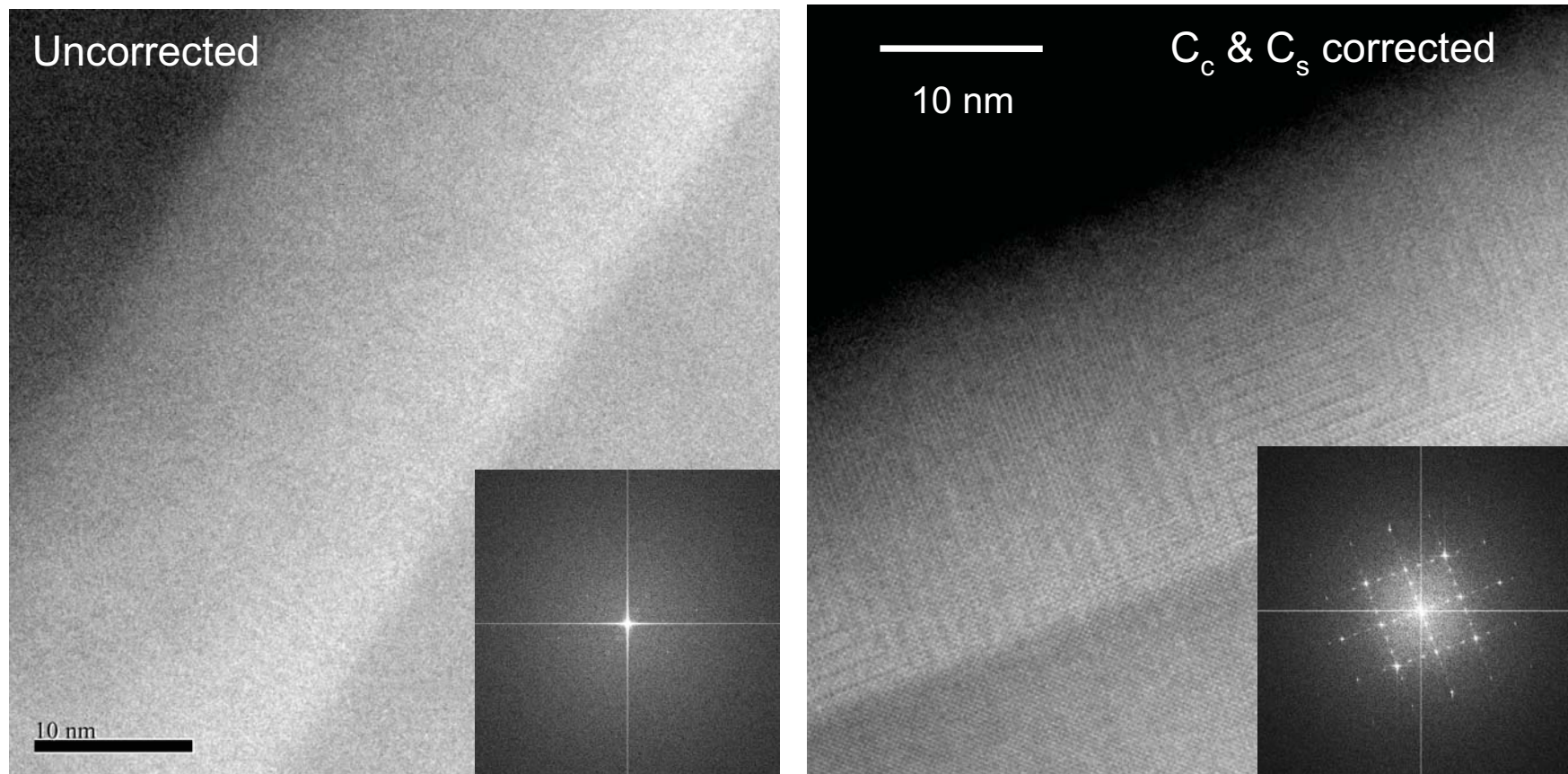
Uncorrected



$C_c$  &  $C_s$  corrected

# World's first energy filtered TEM using chromatic aberration correction

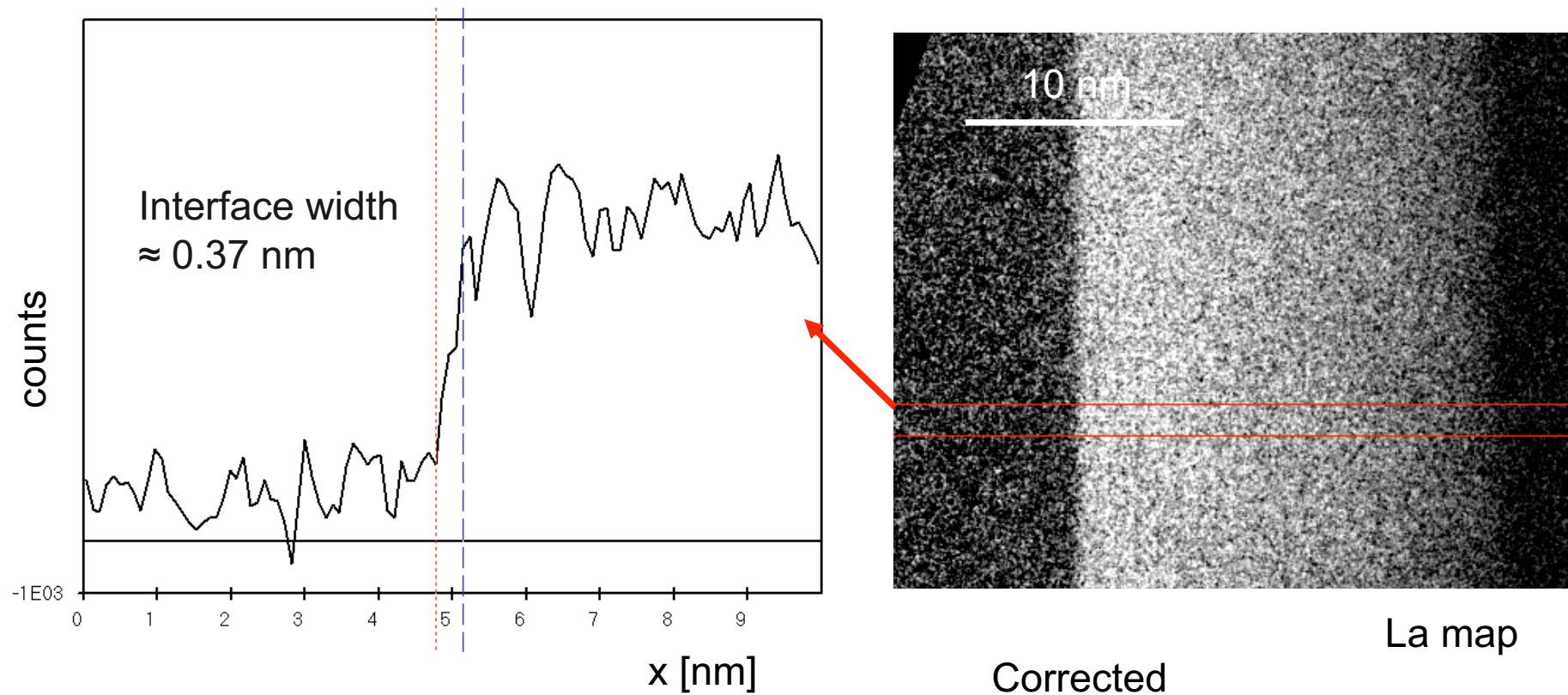
## TEAM $C_c$ -corrector prototype



Energy filtered imaging



# Towards 3-D atomic scale chemical imaging



**TEAM C<sub>c</sub>-corrector prototype**

# Potential impacts of “remote” TEAM

- provide new scientific opportunities for users through TEAM capabilities
  - a benefit in “passive” mode
  - “active” mode allows research teams to work together as usual yet take advantage of new resources
- new capabilities and optimization of TEAM can be transferred to all users via remote control
  - creates a network of “local” experts

